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COMPARISON AND EVALUATION OF SURFACE AND MECHANICAL CHARACTERISTICS OF CARBON FIBRE PETG WITH POLYLACTIC ACID AND ACRYLONITRILE BUTADIENE STYRENE

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Original Article

ABSTRACT

Additive manufacturing process is a very fast and upcoming field, where the materials used are becoming vastly diverse in the properties and application areas, with the most common materials being Acrylonitrile butadiene styrene (ABS) and Polylactic Acid (PLA) with their unique 3D printing settings and drawbacks. With higher usage of 3D printed parts being used as functional elements, better thermal and mechanical characteristics have become necessary. Carbon fibre is one material that has been known for its mechanical properties. But printing carbon fibre with the conventional printers is very difficult. So, it is either used to reinforce ABS or PLA materials and improve their thermal mechanical and chemical properties. A Carbon Fibre Polyethylene Terephthalate Glycol (CF PETG) with a printer, that is designed to print CF PETG, ABS and PLA with similar settings. This study deals with the printing of the test models with the 3D printer and test the print quality for surface measurement, metrological accuracy and bonding quality using microscopy. These results are compared with the same model printed with ABS and PLA.

KEYWORDS: Carbon Fibre PETG, ABS, PLA, 3D Printing & Surface Roughness

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1. INTRODUCTION

In the current growth in additive manufacturing process for rapid prototyping and engineering applications, newer materials are required to fulfill the drawbacks of the existing materials. Fiber reinforced materials show better mechanical properties [1][2]. These materials are mostly printed using Fused Deposition Modelling (FDM) process, where the materials are deposited through the nozzle in the form of layers and each layer is extruded in a parallel pattern [3][4]. There are other methods for printing carbon fiber reinforced plastics and composites like SLA, which uses liquid photo polymer and other techniques using starting materials in powder state like SLS and 3DP. These methods were described by X. Wang et al. as shown in the figure 1[5] [6].

Halil et al. investigated on short fiber reinforced ABS for mechanical properties and microscopic study revealed that they had around 115% improvement in the tensile strength and around 700% improvement in their modulus compared to the traditional compression molding techniques to produce the same[7].

Max James Sauer's work shows that the short fibers with higher infill densities had higher tensile strengths and moduli [8]. His work also mentions that the continuous fiber loaded longitudinally within the part showed increase in the tensile strength and moduli, while others provided little to no reinforcement[8].

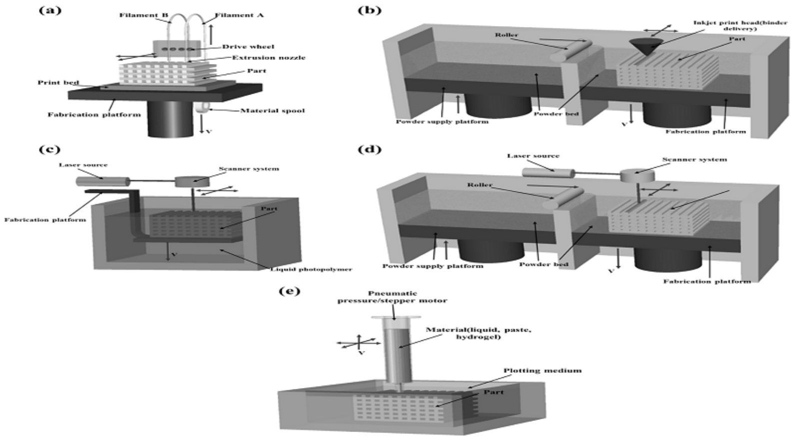

Figure 1: Schematic Representation of a) FDM Setup, b) 3DP Setup, c) SLA Setup, d) SLS Setup, e) 3D Plotting Setup[5][6].

A comparison was made by Kovan V et al., comparing the mechanical properties of PLA with 15% carbon reinforced PLA showed better results with pure PLA than the carbon reinforced one [9]. This effect was in contrast to the theoretical belief resulting in the need for this project and comparison. Similarly, Yuhang Li et al. compared new composites of PLA with a carbon fibre reinforced one and came out with better mechanical characteristics on the latter, but with poor bonding strength and also showed higher porosity on the printed product, as observed under SEM microscopy [10]. Huseini S. Patanwala et al., used carbon nano tubes – PLA aggregates and found out that the Young's modulus increased by 30% with 5% CNT, but there was significant drop in the tensile strength and toughness of the printed products [11]. This urges the need for mechanical testing of the carbon fiber PETG material. The present work aims at printing a gear designed with CAD software using carbon fiber PETG, polylactic acid (PLA) and Acrylonitrile Butadiene Styrene (ABS). Then the prints are tested for surface measurement, surface hardness followed by surface microscopy to observe the layer bonding in each material.

2. EXPERIMENTAL PROCEDURES

A printer was custom fabricated to print all the 3 materials trying to avoid wear to the nozzle, clogging possibilities and match the appropriate printing speed. A common mechanical structure has to be printed to check for the dimensional and geometric accuracy. Figure 2 shows a spur gear with module 3 mm, chordal thickness around 4.7 mm and 20 tooth designed using solid works. This design was converted to stl file and printed using Cura software.

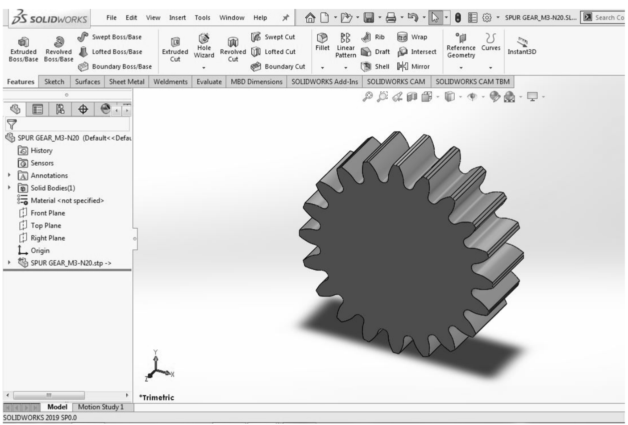

Figure 2: Spur Gear Design – Solid Works.

2.1 Printing with PLA

PLA is very commonly used in 3D printing, as it is easily available and can be used in replaceable parts. But a known drawback of this material is that, it is very brittle and is prone to thermal and mechanical wear and tear, thus leading to the part's damage. But, this material is known to show good print geometric accuracy. This can be a better comparison element for the evaluation of carbon fiber PETG. The following *table 1* shows the print properties of a PLA material set to print the model.

Table 1: Print Settings for PLA

Material Type	Polylactic Acid (PLA)
Density	1.24 g/cm^3
Material diameter	2.85 mm
Printing Temperature	200 deg. Celsius
Build plate temperature	60 deg. Celsius
Fan Speed	100%

2.2 Printing with ABS

ABS is one of the commonly used 3D printing material, known for its rigidity and mechanical properties. So, ABS was chosen as a comparison element to evaluate the carbon fiber PETG material. The following *table 2* shows the print properties of a ABS material set to print the model.

Table 2: Print Settings for ABS

Material Type	Acrylonitrile Butadiene Styrene (ABS)
Density	1.10 g/cm^3
Material diameter	2.85 mm
Printing Temperature	225 deg. Celsius
Build plate temperature	80 deg. Celsius
Fan Speed	0%

2.3 Printing with Carbon Fiber PETG

Carbon fiber PETG is an enhanced version of the Polyethylene Terephthalate Glycol (PETG) material. This material cannot be printed in regular printers as it requires higher temperatures and better nozzle properties. *Table 3* shows the print settings for the carbon fiber PETG material.

Table 3: Print Settings for Carbon Fiber PETG

Material Type	Carbon fibre PETG
Material diameter	1.75mm
Printing Temperature	240 deg. Celsius
Build plate temperature	100 deg. Celsius
Fan Speed	0%

2.4 Geometric Accuracy

The printed models were tested for their geometric accuracy. The gear dimensions are compared with the solidworks model and corresponding practical measurements were taken on each printed models.

2.5 Surface Testing

The surface roughness of the three materials were analyzed using a surface roughness tester. The individual print layers were observed in the surface roughness perspective.

2.6 Surface Microscopy

The printed objects were observed under optical microscope and compared. The indents made by the hardness test were also observed to inspect for crack formation or damage.

2.7 Hardness Testing

The ABS and Carbon fiber PETG materials were tested for their hardness using a digital Rockwell hardness testing setup. The PLA material was excluded from this test to avoid damage to the model.

3. RESULTS & DISCUSSIONS

The geometric accuracy of the print was compared to the actual CAD file as seen in the *figure 5*&*figure 6* to measure the major and minor diameters.

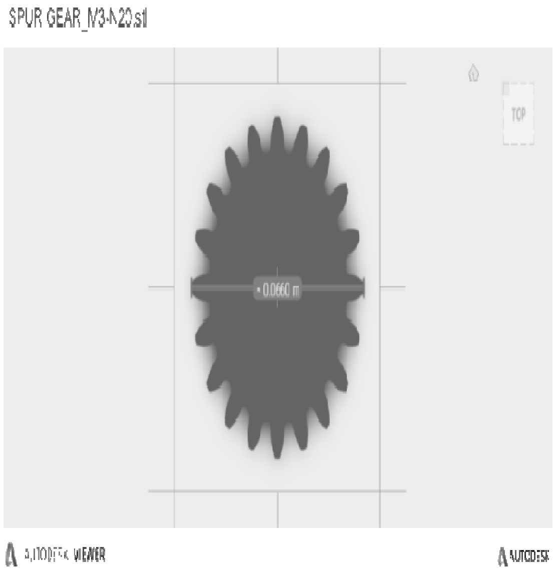

Figure 5: Major Diameter of the Model.

Figure 6: Minor Diameter of the Model.

The module was used to calculate the chordal thickness value to be around 4.7mm. This value was compared with the three printed models. The readings were obtained using machine vision and chordal thickness was measured as a mean value obtained through both machine vision and gear tooth Vernier. The geometric measurements taken through machine visionresulted in the process as seen in *figure 7*. The results are tabulated in the following *table 4*.

Table 4: Geometric Analysis of the Gear Models Across Three Trials

	Major Diameter (in mm)			Minor Diameter (in mm)			Chordal Thickness(in mm)		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
Theoretical value	66.0	66.0	66.0	52.3	52.3	52.3	4.7	4.7	4.7
ABS	65.88	65.87	65.83	52.19	52.26	52.26	4.66	4.64	4.68
PLA	65.84	65.82	65.82	52.22	52.24	52.18	4.61	4.59	4.57
Carbon fiber PETG	65.91	65.93	65.92	52.28	52.26	52.28	4.66	4.66	4.68

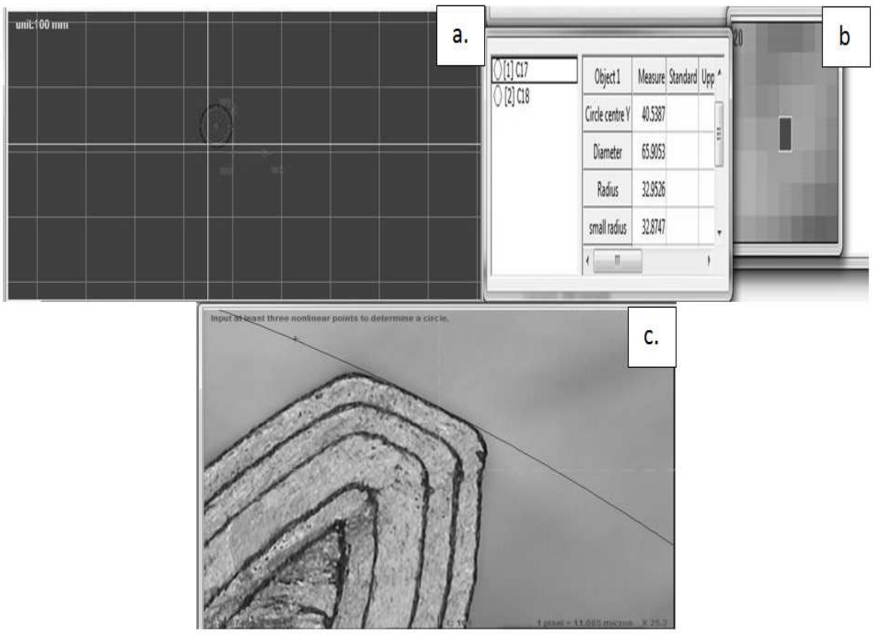

Figure 7: Machine Vision to Measure the Geometric Accuracy of the Printed Models. (a) Major and Minor Diameters Marked through Non-Linear Points on the Gear in Machine Perspective (b) Major Diameter Measured on Carbon Fiber PETG Model with Descriptive Measurement Data. (c) Major Diameter Marked by Selecting Non-Linear Points on the Carbon Fiber PETG Model.

The three models were tested for surface roughness resulting in figure 8, figure 9, figure 10, figure 11, figure 12 and figure 13.

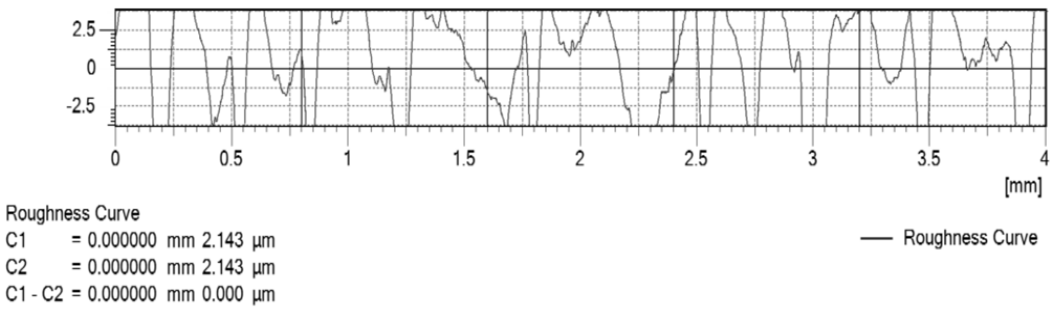

Figure 8: Roughness Curve – ABS.

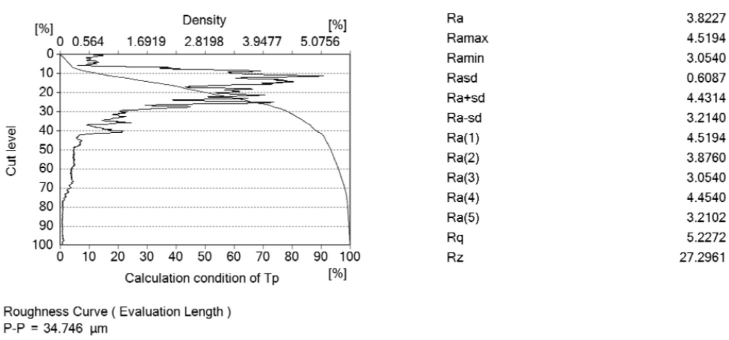

Figure 9: Density Vs Cut Level – ABS.

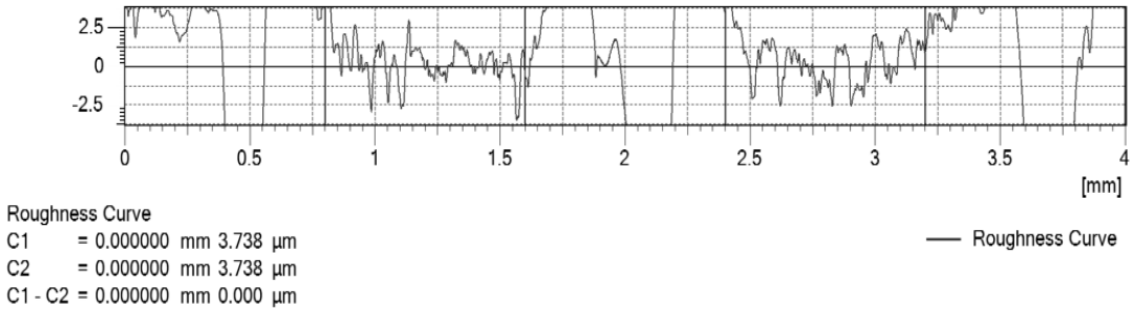

Figure 10: Roughness Curve –Carbon Fiber PETG.

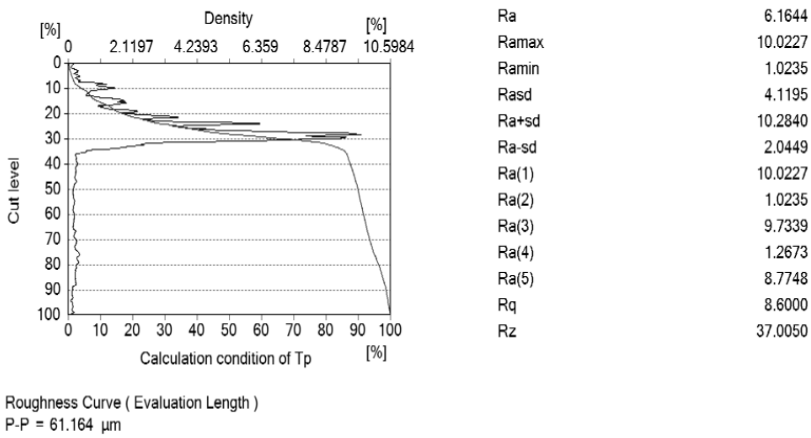

Figure 11: Density Vs Cut Level – Carbon fiber PETG.

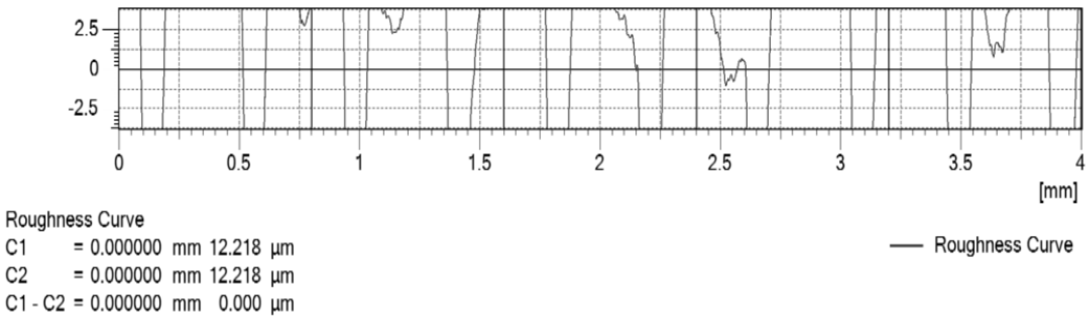

Figure 12: Roughness Curve –PLA.

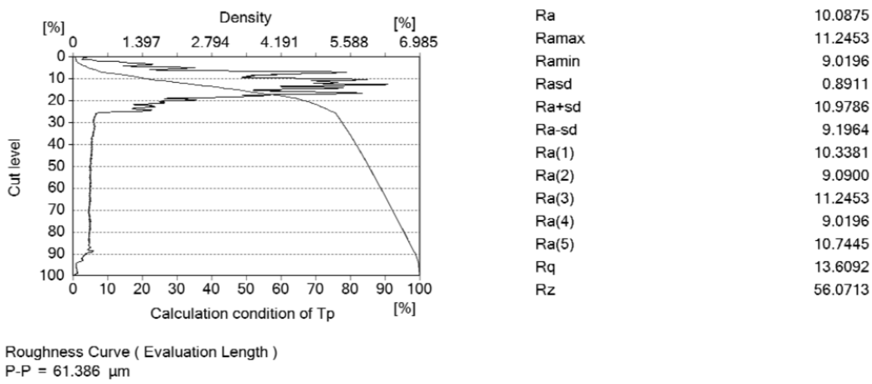

Figure 13: Density Vs Cut Level – PLA.

It was fairly evident from the results that the ABS and Carbon fiber PETG had better surface finish than the PLA material, as the distance between each layer is much significant. Upon surface microscopy inspection the layer bonding was inspected in the three materials as shown in the *figure 14, figure 15, figure 16, figure 17, figure 18 and figure 19.*

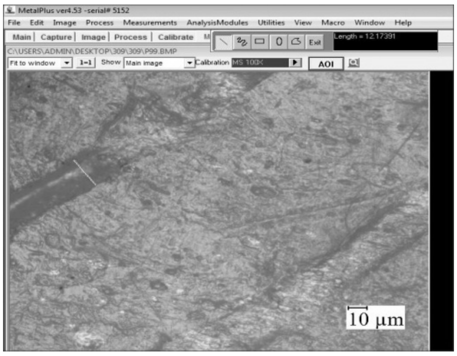

Figure 14: Surface Microscopy of PLA with Layer Measurement.

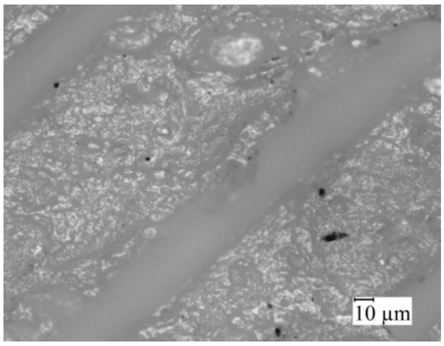

Figure 15: Surface Microscopy of PLA Material.

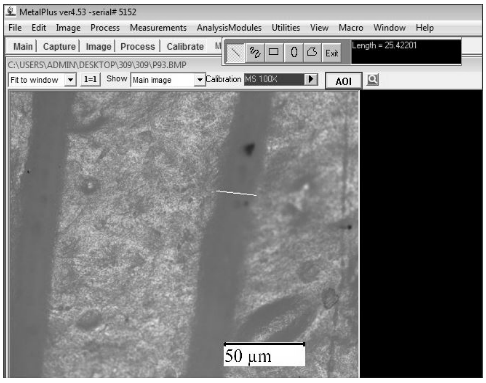

Figure 16: Surface Microscopy of ABS with Layer Measurement.

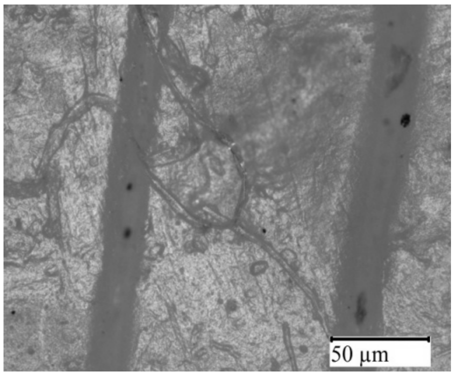

Figure 17: Surface Microscopy of ABS Material.

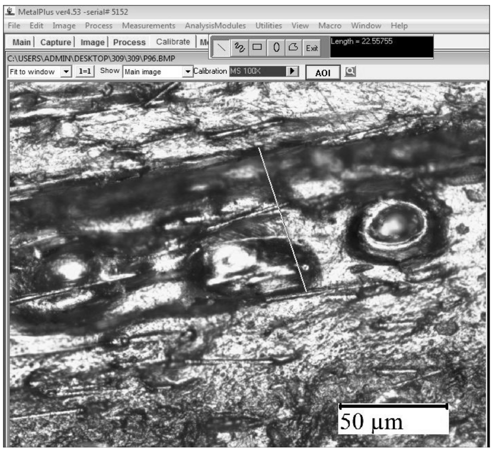

Figure 18: Surface Microscopy of ABS with Layer Measurement.

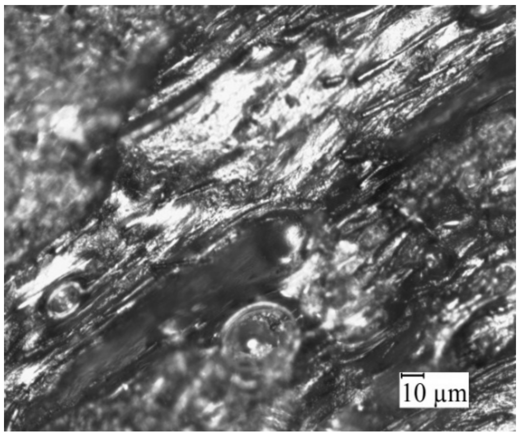

Figure 19: Surface Microscopy of ABS Material.

The Rockwell hardness was performed on ABS and carbon fiber PETG. The ABS model resulted in 38.6 HRB and 40 HRB upon average on 8 trials, while the carbon fiber PETG resulted in 32 HRB and 31.8 HRB upon average on 8 trials. It can be inferred that the carbon fiber PETG shows better mechanical properties, but requires some major changes in

the printing setting and extrusion setting to make smoother and tougher printed components devoid of the thermal flaws and air holes.

4. CONCLUSIONS

From the results, it was found that the carbon fiber material had good weight to hardness ratio, as it weighed 32.6416 g and resulted in around 32 HRB when a ball indent was used at 60 kgF. ABS weighed 56.591 g and resulted in 40 HRB, thus showing better mechanical characteristics.

Upon the surface inspection, the ABS and PLA smoother layers, but had average to below average layer bonding. The carbon fiber PETG model had many surface flaws and showed poorer surface smoothness. But the layer bonding of carbon fiber PETG was much better than the ABS or PLA.

Upon the geometric testing, almost all the materials rated the same. The PLA showed more warping, while the ABS and carbon fiber better resistance against warping. As a future scope, the printing methodology can be varied to get better surface finish in carbon fiber PETG and a comparison of the settings can help in knowing the material better, and such printer can be very useful in the engineering and research process through rapid prototyping.

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